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Soil properties and nutrient relations in burned and unburned Mediterranean-climate shrublands of Baja California, Mexico

Ernesto Franco-Vizcaíno (*) and Joaquín Sosa-Ramirez (**)

(*) *Department of Crop and Soil Sciences, Plant and Soil Sciences Building, Michigan State University, East Lansing, MI 48824-1325, USA, and Departamento de Ecología, Centro de Investigación Científica y de Educación Superior de Ensenade (CICESE), Apartado Postal 2732, Ensenada, Baja California, México.*
(**) *Departamento de Ecología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Apartado Postal 2732, Ensenada, Baja California, México.*

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Abstract

We compared soil chemical properties and total N and P in ecosystem compartments (soil, litter, root, stem, and leaf) of adjacent burned and unburned shrublands in northwestern Baja California during the first annual cycle after burning. We sampled one stand of coastal sage scrub growing on soil derived from basalt, and two stands of mixed chaparral growing on soils developed from granitic rocks. In the coastal sage scrub site, total soil N (1350-2140 mg/kg) and P (360-540 mg/kg) were similar to concentrations reported for Mediterranean-climate shrublands growing in fertile soils of Alta California (USA), Chile and the Mediterranean Basin. But at the chaparral sites, total soil N (750-1180 mg/kg) and P (90-150 mg/kg) were as low as those of the relatively infertile Australian heath. There was no significant reduction in organic C, nor increase in pH or salinity, in the burned areas. Only inorganic N was slightly, but significantly, higher in the soil of all three burned areas. No significant differences were found in total N or P between burned and unburned ecosystem compartments across the three sites when the entire annual cycle was considered. But N was significantly higher in leaves and stems of burned areas, although only briefly during the middle of the first growing season after fire. Nutrient enrichment following wildland fire was thus less pronounced and more transitory than is typically reported for burned shrublands in Alta California. Fire suppression has not been effective in Baja California, and fuel loads and fire intensities tend to be lower than in Alta California. Lower fuel loads and fire intensities, and consequently lower ash deposition, may partly explain the lack of marked differences in soil properties found between burned and unburned areas.

Keywords: Widland fire, soil properties, parent materials, nutrient dynamics, coastal sage scrub, chaparral, matorral, Mediterranean-type ecosystems, nitrogen, phosphorus.

Résumé

Nous avons étudié les propriétés chimiques du sol et les N et P totaux de compartiments de l'écosystème (sol, litière, racine, tronc et feuille) de milieux arbustifs adjacents, brûlés et non brûlés, dans le nord-ouest de la Basse Californie au cours du premier cycle annuel après le feu. Nous avons échantillonné une parcelle de matorral côtier sur un sol dérivé du basalte et deux parcelles de chaparral mixte sur des sols issus de roche granitique. Sur le matorral côtier, le N (1350-2140 mg/kg) et le P (360-540 mg/kg) totaux du sol sont similaires aux concentrations mentionnées pour des milieux

arbustifs de climat méditerranéen sur des sols fertiles de Californie (USA), du Chili et du bassin méditerranéen. Mais sur le site à chaparral, le N (750-1180 mg/kg) et le P (90-150 mg/kg) totaux du sol sont aussi faibles que ceux de landes australiennes relativement infertiles. Il n'y a pas de réduction significative du C organique, ni d'augmentation du pH ou de la salinité dans les zones brûlées. Seul le N inorganique est légèrement, mais significativement plus élevé dans les sols des trois zones brûlées. Nous n'avons pas trouvé de différence significative du N ou du P totaux entre les compartiments brûlés et non brûlés de l'écosystème, sur l'ensemble des trois sites lorsque le cycle annuel est considéré dans son entier. Mais N est significativement plus élevé dans les feuilles et les troncs des zones brûlées, bien que seulement, brièvement, en milieu de première saison de croissance après le feu. L'enrichissement en nutriments consécutif au feu est donc moins prononcé et plus transitoire que cela n'est mentionné classiquement pour les milieux arbustifs brûlés de Californie (USA). La suppression des incendies n'a pas été effective en Basse Californie et les quantités de combustible ainsi que les intensités des incendies ont tendance à être plus faibles qu'en Californie (USA). Des quantités de combustible et des intensités de feu plus faibles, et par conséquent un plus faible dépôt de cendres, pourraient expliquer en partie l'absence de différences marquées des propriétés du sol entre les zones brûlées et non brûlées.

INTRODUCTION

Nitrogen and phosphorus are the most important nutrients limiting the productivity of Mediterranean-climate vegetation (DEBANO *et al.*, 1977; RUNDEL, 1983). Because of desiccation during summer drought, Mediterranean-type shrublands are susceptible to burning. Fire may be largely responsible for decomposing organic matter and releasing nutrients for cycling. Burning results in losses of N by volatilization, but P and other nutrients are generally deposited back onto the soil in ash, where they are vulnerable to loss by erosion and leaching (CHRISTENSEN & MUELLER, 1975; DEBANO *et al.*, 1977; DEBANO & CONRAD, 1978; DEBANO *et al.*, 1979; WIENHOLD & KLEMMEDSON, 1992; CHRISTENSEN, 1994). Many workers have reported that this surface enrichment results in temporary increases in tissue nutrient concentrations and growth rates (ZINKE, 1977; DEBANO *et al.*, 1977; CHRISTENSEN, 1994).

In North America, Mediterranean-climate ecosystems occur along a gradient of high-to-low precipitation from Oregon to Baja California. Management of wildlands differs in at least two respects between Alta (USA) and Baja California (Mexico): fires are effectively suppressed in Alta but not in Baja California, and grazing intensity is much lower in Alta than in Baja California. Because of fire suppression in Alta California, biomass accumulates, and the resulting fuel load feeds intense fires that are difficult to control when they do take hold (*e.g.* during dry and windy "Santa Ana" conditions). Fire intensity is usually lower in the more frequently burned vegetation of Baja California (MINNICH *et al.*, 1993). Such differences in climate and management, as well as differences in the composition of soil parent materials, may cause differences in the levels of nutrients in soils and plant tissues. However, little information is available on the fertility of soils or nutrient relations of Mediterranean-climate shrublands in Baja California.

The aims of this study were i) to compare soil properties and N and P concentration in ecosystem compartments in burned and unburned coastal sage scrub and chaparral during the first annual cycle after burning, and ii) to compare the fertility of soils that support Mediterranean-type shrublands in Baja California with results previously reported in the literature for Alta California and other Mediterranean-climate regions.

MATERIALS AND METHODS

Study sites

We selected study sites on the basis of having adjacent burned and unburned areas on similar soils (table I) in one coastal sage scrub, and two mixed chaparral stands near Ensenada, Baja California. Species composition was consistent with classification and mapping of the major plant communities of Baja California (R. A. MINNICH, personal communication). Because it was necessary to sample species common to both burned and unburned study plots, not all species selected for sampling were among the three or four most dominant species at each site. The sampling plots, which were approximately 20 × 20 m, appeared to have had uniformly mature vegetation prior to burning. Both chaparral sites burned in the same event early in September 1988. The date of the Las Chichihuas fire is unknown, but it also occurred during summer 1988.

Las Chichihuas is on a low plateau approximately 10 km from the Pacific Ocean, while El Colgado and El Mogor are on steep hillsides approximately 25 km inland, and some 10 km east of the first range of coastal hills. The climate is typically Mediterranean, with cool, moist winters and warm, dry summers (fig. 1). This study was conducted during a prolonged drought, and precipitation during 1989 was about one-third the annual average. During the study period (20 Jan 89-15 Feb 90), a total of 242 mm of rainfall was registered at the Mesa El Tigre weather station, some 3 km south of the coastal sage scrub site, but only 96 mm fell during all of 1989. Similarly, 196 mm of rainfall were recorded during the study period at Olivares Mexicanos, which is about 3 km northwest of the chaparral sites, with 92 mm falling during 1989. As a result of drought during the study period, germination and establishment of annuals was sparse and most of the new growth in the burned areas was by resprouting from burned stumps and root crowns.

METHODS

Samples were taken from ecosystem compartments: soil, litter, roots, stems, and leaves in burned and unburned areas, as proposed by RUNDEL (1978). Three perennial species were sampled at each site, and tissue samples were bulked from 3-5 individuals of the same species in each plot. Data from each species were treated as replicate measurements at each site. Only one species, *Malosma laurina*, was common to burned and unburned areas at all three sites. Soil (0-10 cm) and litter samples (n = 3) were collected by pooling from area ~ 1 m^2 at 1-2 m from shrub crowns or burned stumps. For purposes of comparison, ash was collected in the burned areas when litter was unavailable. Samples were taken at the beginning (1/20/89), middle (3/9/89), and end of the rainy season (5/30/89), as well as during the summer drought (8/2/89) and after the beginning of the following rainy season (2/15/90). The chaparral sites were not selected until the second sampling date, but during subsequent samplings all three sites were sampled within two days of the above dates. Rainfall records for the summer and fall of 1988 indicate that some 60 mm had fallen at the coastal sage scrub site prior to the time of first sampling there, and approximately 80 mm had fallen at the chaparral sites prior to first sampling. Although the properties of ash and soil may have been altered by leaching and erosion, rainfall events were mostly less than 10 mm and those effects were likely small.

Soil and ash samples were air dried as soon as possible and stored in polyethylene bags and then sieved (2 mm) prior to analysis. Plant tissue samples were dried (105°C), ground in a spice mill, and stored in polypropylene bottles. Subsamples of tissue were finely ground and total N and P were determined in the Kjeldahl digest. Laboratory procedures for the determination of soil properties were generally as in PAGE *et al.* (1982). In soils and ash, total N was determined by the Kjeldahl procedure, but

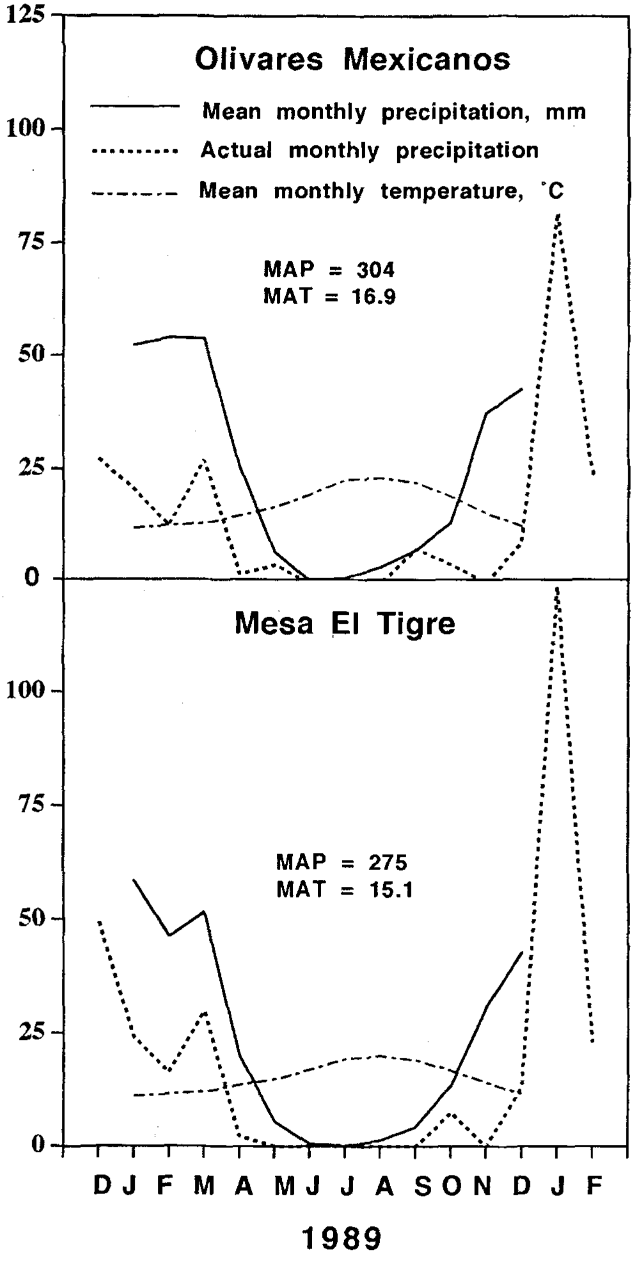

Fig. 1. – Climate characteristics, and precipitation during the study period, recorded at the weather stations nearest the chaparral sites (Olivares Mexicanos) and the coastal sage scrub site (Mesa El Tigre). Data are from Secretaría de Agricultura y Recursos Hidráulicos, División Hidrometrica, Ensenada, Baja California. Years of record for mean annual precipitation (MAP) and temperature (MAT) are 1957-1989.

TABLE I. – *Characteristics of study sites in adjacent burned and unburned Mediterranean shrublands near Ensenada, Baja California, Mexico.*

Site Location	Landscape position & aspect (% slope)	Plant community	Parent material Soil depth (cm)	Altitude (m)	Species sampled	Soil classification	Soil texture[a] (% sand silt, clay)	CEC[b] (meq/100g) Base sat. (%)
Las Chichihuas 116° 45′ W 32° 01′ N	Dissected lava flow N (20%)	Coastal Sage Scrub	Basalt (32)	300	*Artemisia californica* *Malosma laurina* *Salvia apiana*	fine-loamy, mixed, thermic Lithic Haploxerolls	Loam (49, 30, 21)	28.9 59.7[c]
El Colgado 116° 33′ W 32° 03′ N	Midslope NW (25%)	Mixed Chaparral	Granitic (120+)	550	*Ornithostaphyllos oppositifolia* *Xylococcus bicolor* *Malosma laurina*	clayey-skeletal, montmorillonitic, thermic Typic Argixerolls	Sandy loam (69, 20, 11)	16.3 71.9[d]
El Mogor 116° 36′ W 32° 02′ N	Midslope NW (45%)	Mixed Chaparral	Granitic (27)	500	*Fraxinus trifoliata* *Cneoridium dumosum* *Malosma laurina*	loamy, mixed, thermic, shallow Typic Haploxerolls	Sandy loam (75, 14, 11)	10.3 77.0[e]

total P was obtained by digesting with concentrated nitric-perchloric acids. Plant-available (extractacle) N in soils was determined by extracting NO_3^--N and NH_4^+-N with 2 *M* KCl.

The concentrations of N and P in the digest and N in the KCl extract were measured by automated colorimetry (QuikChem, Lachat Instruments, Milwaukee, Wisconsin). Subsamples of soil were saturated with deionized water, and pH was measured in the saturated paste. Electrical conductivity was measured in saturation extracts (EC_{se}). The concentrations of P, K, Mg, Ca, and Na in the saturation extract (that is, soil solution) were measured by plasma spectrometry (DCP) (SpectraSpan VB, Fisons Instruments, Danvers, Maryland). In addition, organic C was determined by the Walkley-Black procedure, and soil texture by the hydrometer method. Data were analyzed by repeated measures ANOVA using the Stat View 4.0 statistical analysis program (Abacus Concepts, Berkeley, California). Additional soils data (bulk density, cation-exchange capacity, base saturation, field classification) were obtained in 1993 in an unrelated study (Franco-Vizcaíno *et al.*, 1994, and unpublished data).

RESULTS AND DISCUSSION

Soil properties

At all three study sites, soils were non-saline (EC_{se} = 0.7-1.0 dSm^{-1}, data not shown), and ranged from slightly acid to neutral (table II). The individual concentrations of P, K, Mg, Ca, and Na were measured in the saturation extract, but for simplicity only data for P and the sum of cation concentrations are shown. Concentrations of the major cations in the soil solution were generally low; but only the concentrations of Mg in the soil solution (1.0-3.5 mg L^{-1}) were lower than the minima reported for agricultural soils in Alta California (Bradford *et al.*, 1971). Low Mg concentrations in the soil solution have previously been reported for Baja California shrublands (Franco-Vizcaíno & Khattak, 1990), but cations have not been reported to limit the productivity of Mediterranean-climate shrublands (Rundel, 1983).

Except for the burned area at El Mogor, mean annual extractable N was only slightly higher than that reported for *Adenostoma* chaparral (17 mg/kg) at the International Biological Program study site at Echo Valley, California (Mooney & Rundel, 1979). Clay contents, cation exchange capacities, and base saturations reported in the present study (table I) are similar to those reported for the soil at Echo Valley (Miller *et al.*, 1977).

Averaged over the annual cycle, total N and P concentrations in the soil of the coastal sage scrub (tables III, IV) were within the ranges reported for the relatively fertile soils that support the shrublands of Alta California, Chile and the Mediterranean Basin (Specht, 1969; Rundel, 1978; Christensen, 1994). But mean total soil P at the chaparral sites (90-150 mg kg^{-1}) was as low as that reported for the relatively infertile soils of Australian heath and, on individual dates, P was nearly as low as that of the South African fynbos. A subsequent study across 24 sites on six different parent materials confirmed that soils that support shrublands in coastal Baja California are generally low in total P, the majority falling in the range between 50 and 200 mg P/kg (unpublished data).

On an areal basis, total soil N (0-10 cm layer, averaged over time and burn status) was 218 g m^{-2} at Las Chichihuas, and 142 and 117 g m^{-2} at El Colgado and El Mogor, respectively. This is higher than the 90 g m^{-2} reported for Echo Valley (Mooney & Rundel, 1979). But while total soil P at Las Chichihuas was 69 g m^{-2}, similar to 75 g m^{-2} at Echo Valley, the corresponding values for El Colgado and El Mogor were

Table II. – *Within-site comparisons of soil properties (0-10 cm) in burned and unburned shrublands during the first yearly cycle after burning.*

	Burned				Unburned				LSD[a]	
Date	3/9/89	5/30/89	8/2/89	2/15/90	3/9/89	5/30/89	8/2/89	2/15/90	Burn Status	Between Dates
					Coastal Sage Scrub					
Las Chichihuas										
pH	6.5	6.4	6.5	–	6.4	6.3	6.6	–	0.1ns	ns
Organic C[b]	3.00	2.27	2.19	2.19	3.41	2.12	3.38	2.89	0.57#	#
Extractable N[c]	19.3	26.7	19.7	54.2	22.2	29.4	24.1	11.3	6.9*	ns
Total Cations[de]	22.0	17.7	16.8	47.5	20.2	16.1	17.3	19.1	18.0ns	ns
P[d]	3.36	2.36	2.03	1.62	2.32	3.04	2.45	1.44	1.02ns	#
					Mixed Chaparral					
El Colgado										
pH	6.6	6.8	6.8	–	6.3	6.5	6.5	–	0.3ns	ns
Organic C[b]	3.04	3.07	2.36	2.98	2.36	2.62	3.48	4.41	1.68ns	ns
Extractable N[c]	19.8	34.7	26.7	37.7	17.2	20.5	22.8	26.8	3.68*	ns
Total Cations[de]	20.0	18.5	19.7	14.3	13.6	16.1	20.5	11.6	3.06*	ns
P[d]	2.04	1.78	0.98	trace	1.40	1.11	3.64	1.01	1.39#	**
El Mogor										
pH	6.6	7.0	6.7	–	6.4	6.9	6.9	–	0.2ns	**
Organic C[b]	2.27	2.52	2.69	2.67	1.54	1.90	2.49	1.70	1.16ns	ns
Extractable N[c]	19.1	19.4	25.8	21.4	9.6	15.0	13.1	7.28	3.22***	ns
Total Cations[de]	14.3	18.2	16.8	17.0	16.4	16.3	19.3	17.3	8.27#	ns
P[d]	2.16	3.32	1.76	3.23	2.35	2.07	1.54	2.69	1.37ns	ns

Values are averages (n = 3). [a] Least significant difference estimated by repeated-measures ANOVA for the period March '89-February '90. [b] per cent; [c] mg (NO_3^--N + NH_4^+-N)/kg; [d] mg/L in saturation extract; [e] sum of K^+, Mg^{2+}, Ca^{2+}, and Na^+; #, *, **, *** significant at the $P \leq 0.10$, 0.05, 0.01, and 0.001 levels, respectively; ns denotes $P > 0.10$.

TABLE III. – *Within-site comparisons of total nitrogen concentration in ecosystem compartments of burned and unburned shrublands during the first yearly cycle after burning.*

	Burned					Unburned					LSD[a]	
Date	1/20/89	3/9/89	5/30/89	8/2/89	2/15/90	1/20/89	3/9/89	5/30/89	8/2/89	2/15/90	Burn Status	Between Dates
	mg N/kg											
	Coastal Sage Scrub											
Las Chichihuas												
Leaf	21070	28570	8620	11940	17160	12000	19900	6860	10610	18510	10640ns	**
Stem	9000	9550	4650	7240	8940	4900	6330	5330	7100	10000	5420ns	ns
Root	6190	4970	10510	5610	7810	5870	3670	16520	4970	6840	2540ns	***
Litter	–	3730	5700	6890	–	–	4810	1690	6940	3360	3520ns	*
Soil	2180	1110	1740	625	1090	2700	2010	2930	1080	1960	990ns	#
	Mixed Chaparral											
El Colgado												
Leaf	–	18990	10810	6790	2220	–	8130	7860	5830	1730	4230*	***
Stem	–	10590	5300	2970	1240	–	2660	5490	3610	4790	3580ns	*
Root	–	3180	1960	2410	1690	–	3210	3390	4000	1060	3180ns	ns
Litter	–	1840	4850	3560	–	–	7200	7140	3740	2470	1770*	*
Soil	–	546	1520	509	1040	–	872	1850	500	1500	808ns	ns
El Mogor												
Leaf	–	34400	15490	9180	10430	–	13100	5740	7120	9110	14250#	*
Stem	–	16000	6120	5180	5060	–	4460	4770	4760	3230	7910ns	#
Root	–	6100	3320	4400	3640	–	5330	3440	4210	2910	2060ns	***
Litter	–	4320	4140	4260	3780	–	4600	5830	4580	2110	4310ns	*
Soil	–	1230	931	655	1020	–	883	383	892	865	429ns	*

Values are averages (n = 3); tissue values are averages of three perennial species. [a] Least significant difference estimated by repeated-measures ANOVA for the period January-August '89 for Las Chichihuas, and March-August '89 for the two chaparral sites. #, *, **, *** significant at the $P \leq 0.10$, 0.05, and 0.001 levels, respectively; ns denotes $P > 0.10$.

TABLE IV. – *Within-site comparisons of total phosphorus concentration in ecosystem compartments of burned and unburned shrublands during the first yearly cycle after burning.*

	Burned					Unburned					LSD[a]	
Date	1/20/89	3/9/89	5/30/89	8/2/89	2/15/90	1/20/89	3/9/89	5/30/89	8/2/89	2/15/90	Burn Status	Between Dates
	mg P/kg											
	Coastal Sage Scrub											
Las Chichihuas												
Leaf	3100	2580	2180	2220	2840	830	2300	2120	2750	4130	1080ns	ns
Stem	900	2030	1140	2210	1890	870	1400	1020	2590	2780	740ns	**
Root	1430	817	2340	1540	1640	570	533	2620	1590	2110	720ns	***
Litter	–	627	1190	1060	–	–	597	211	1100	728	290ns	ns
Soil	1420	652	185	147	392	890	120	300	270	1110	130*	***
	Mixed Chaparral											
El Colgado												
Leaf	–	1790	1840	874	449	–	460	1060	580	310	810#	ns
Stem	–	1660	1290	952	304	–	260	1250	530	590	770#	ns
Root	–	200	422	553	176	–	200	470	330	180	220ns	*
Litter	–	196	144	179	–	–	400	923	356	181	590ns	ns
Soil	–	57.2	45.7	83.7	209	–	52.7	89.9	79.3	136	352ns	ns
El Mogor												
Leaf	–	4100	2620	1330	2940	–	1080	1110	1460	2310	1700#	ns
Stem	–	2240	2200	1610	1660	–	667	986	1030	1080	619**	ns
Root	–	713	776	799	947	–	1010	940	874	874	683ns	ns
Litter	–	257	170	474	354	–	200	640	684	166	306ns	*
Soil	–	168	117	68.1	254	–	34.3	61.7	73.2	264	57.5ns	ns

Values are averages (n = 3); tissue values are averages of three perennial species. [a] Least significant difference estimated by repeated-measures ANOVA for the period January-August '89 for Las Chichihuas, and March-August '89 for the two chaparral sites. #, *, **, *** significant at the $P \leq 0.10$, 0.05, and 0.001 levels, respectively; ns denotes $P > 0.10$.

much lower: 13 and 18 g m^{-2}. It has been postulated that low levels of soil P may limit biological N fixation and thus keep N levels low (MILLER *et al.*, 1977; WIENHOLD & KLEMMEDSON, 1992). Our results indicate that although soil P may be low in Baja California soils derived from granite, the potential for biological N fixation is similar to that of Australian heath or chaparral in adjacent southern Alta California.

Data reported in tables I-IV compare favorably with frequency distributions of soil properties and nutrient contents in ecosystem compartments reported by ZINKE (1982) for monospecific *Adenostoma fasciculatum* chaparral. Our results indicate that nutrient contents in ecosystem compartments at the coastal sage scrub site were generally higher, but the mixed chaparral sites were generally lower than the median for Alta California chaparral.

Comparisons within sites, burned *vs.* unburned

Comparisons within sites were made by using data from each species, and from the three subsamples of soil, litter and ash, as replicate measurements for each site. Repeated measures ANOVA showed no significant differences ($P \leq 0.05$) in organic C, pH (table II) or electrical conductivity (not shown) of the 0-10 cm soil layer between the burned and unburned areas at any of the three sites. Essentially similar results were obtained (not shown) when the data were analyzed without considering time as a factor, that is by pooling samples in tables II-IV (n = 12 or 15).

The only consistent difference in soil properties between burned and unburned areas was significantly higher extractable N (NO_3^--N + NH_4^+-N) in the burned areas. Also, total major cations in the saturation extract tended to be higher in the burned areas of the chaparral sites ($P \leq 0.10$ and 0.05), but not in the coastal sage scrub. This suggests that the intensity of burning at all three study sites was likely low. Fire intensity has been correlated with both ash depth and enrichment in soil nutrients (RICE, 1993).

During the first season, extractable nitrate was low at all three sites (range 2-4 mg/kg), while ammonium averaged ~ 20 mg/kg (not shown). However, nitrate increased to a mean of ~ 15 mg/kg in February '90, while ammonium declined to ~ 12 mg/kg. Over the yearly cycle, nitrate was significantly higher in the burned areas (LSD 3-5 mg/kg), but ammonium was not. The dynamics of extractable nitrate and ammonium varied among sites, but the overall pattern of increasing ammonium accumulation during the spring and summer of the first season with a shift toward nitrate early in the second season is consistent with the results of other workers (CHRISTENSEN, 1994).

Within-site comparisons revealed no significant differences in N or P content in ecosystem compartments when the entire yearly cycle was analyzed by repeated measures ANOVA. But when only the period March-August '89 was considered (tables III, IV), leaves and stems in burned areas were significantly higher ($P \leq 0.05$) or trended ($P \leq 0.10$) toward higher N and P. These increases in N and P contents in leaves and stems peaked by the middle of the first growing season after burning. Because biomass resprouting after fire is small, higher content of N and P in leaves and stems is unlikely to imply greater nutrient uptake over the burned areas (RUNDEL, 1983). A number of significant differences were found between sampling dates, but only differences in leaf and litter N occurred consistently at all three sites.

Comparisons across sites, burned *vs.* unburned

Averaging N and P concentrations in ecosystem compartments over all three sites revealed time patterns of nutrient content (figs 2*a*, *b*) that were similar to those of indi-

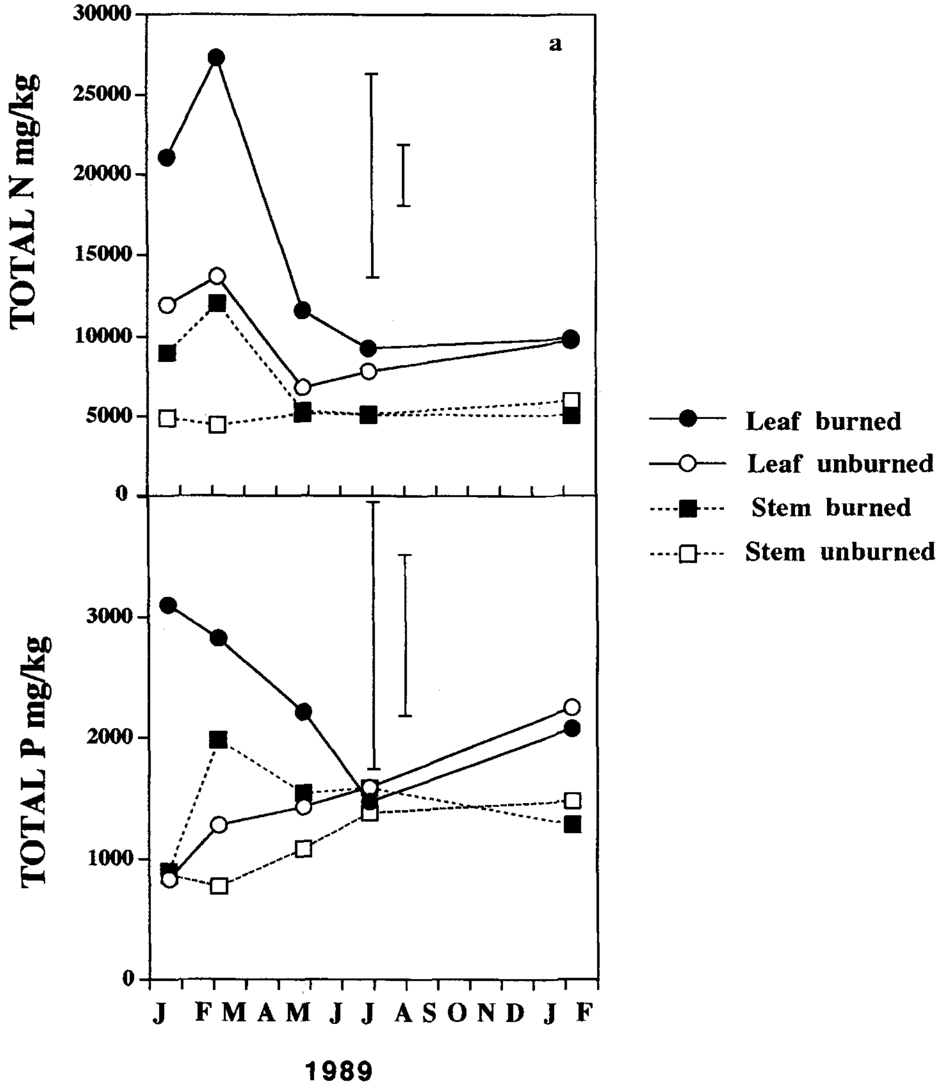

FIG. 2*a*, *b*. – Dynamics of nitrogen and phosphorus concentrations in ecosystem compartments of adjacent burned and unburned Mediterranean-climate shrublands in Baja California. Values are averaged over all three sites: leaves and stems (a) and roots, litter and soil (b). Bars represent the least significant differences (LSD) between burned and unburned compartments, calculated by repeated measures ANOVA for the period March 1989-February 1990 (left to right, a: leaf and stem; b: roots, litter, soil); none is significant at $P \leq 0.05$.

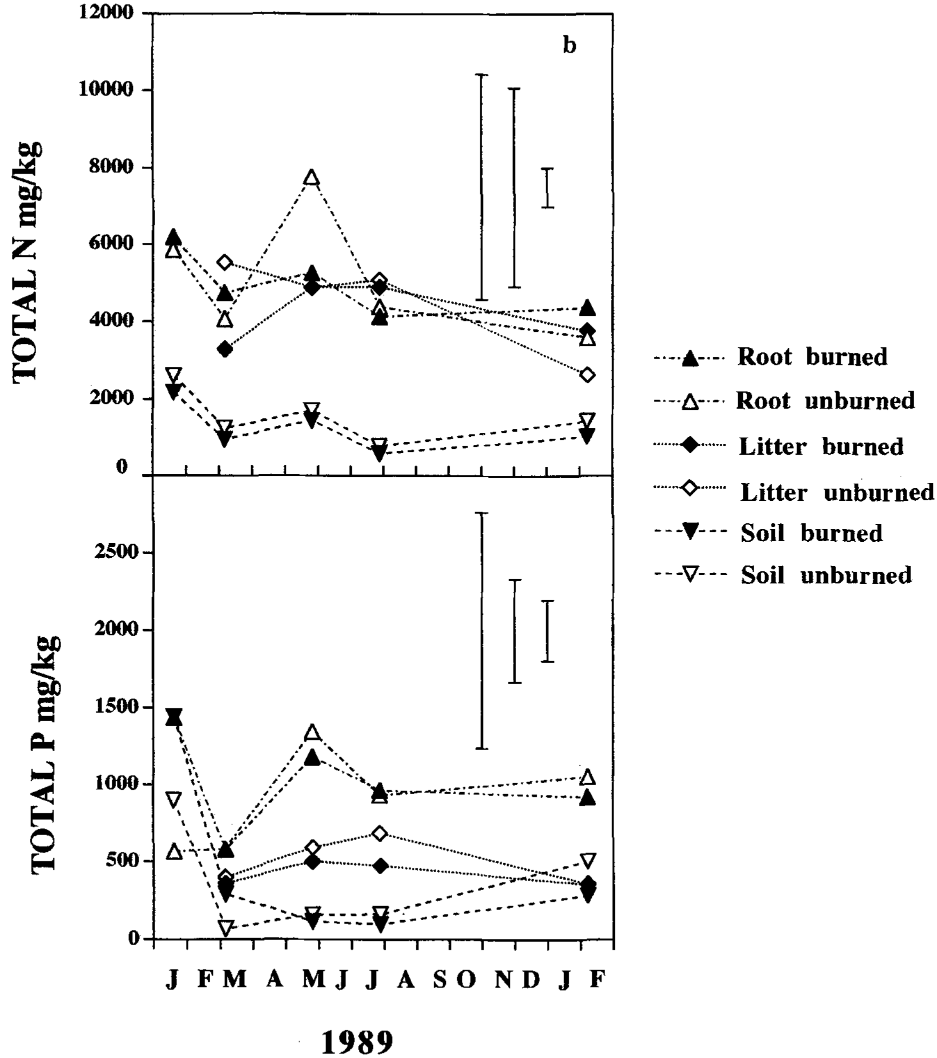

FIG. 2*a*, *b*. – Dynamics of nitrogen and phosphorus concentrations in ecosystem compartments of adjacent burned and unburned Mediterranean-climate shrublands in Baja California. Values are averaged over all three sites: leaves and stems (a) and roots, litter and soil (b). Bars represent the least significant differences (LSD) between burned and unburned compartments, calculated by repeated measures ANOVA for the period March 1989-February 1990 (left to right, a: leaf and stem; b: roots, litter, soil); none is significant at $P \leq 0.05$.

vidual sites (tables III, IV), and individual species (not shown). Nitrogen and phosphorus content peaked during the middle of the growing season, most markedly in leaves and stems, then declined to near initial levels during the summer drought, and remained stable or rose slightly by the beginning of the second season after burning.

Changes through time in N and P content in compartments can be explained by processes such as nutrient uptake by plants, transport to leaves, remobilization and storage in roots, litter deposition, and organic matter decomposition in soils.

In comparisons across sites, pseudoreplication was avoided by using site averages (that is, averaged over all three species and subsamples of soil, litter and ash) for each compartment in the repeated measures ANOVA. No significant differences were found in mean N or P concentrations between burned and unburned compartments when data for the entire yearly cycle were considered (figs 2*a*, *b*). And only leaf and soil N differed significantly between sampling dates (not shown). But the difference between burned and unburned areas in leaf and stem N was larger in March '89 than the corresponding LSD for the yearly cycle. And when only the period March-August '89 was considered, leaf and stem N and stem P were significantly higher ($P \leq 0.05$) in burned areas (not shown).

Similarly, no significant differences were found when data for the entire yearly cycle of *Malosma laurina*, the only species common to both burned and unburned areas at the three sites, were considered (not shown). But when only the period March-August '89 was considered, both N and P were higher in *Malosma laurina* leaves and stems ($P \leq 0.05$) of burned areas. Also, when only the two chaparral sites were considered, no significant differences were found between burned and unburned areas over the yearly cycle, but both leaf and stem N and P were significantly higher ($P \leq 0.05$) in burned chaparral during the period March-August '89 (not shown).

It should be noted that the number and magnitude of differences between burned and unburned ecosystem compartments was site dependent, with several differences or trends in the chaparral sites, but few in the coastal scrub site. In this respect, the ranking was in the same order as that of soil fertility, with the most extreme site, El Colgado, showing the most differences. It is not possible to discern whether this resulted from soil fertility or other factors. While significant differences in N content occurred across sampling dates in most compartments at all three sites, few such differences occurred in P content at the chaparral sites. This may simply reflect the small range in P concentrations at these sites.

Comparisons across sites (fig. 2*b*) showed little evidence of surface enrichment, or "ash-bed" effect (Zinke, 1977), in litter or soils of burned areas; although within-site comparisons revealed some differences at individual sites (tables II-IV). Nor were there consistent losses of organic C or total N in soils, or of N in litter of burned areas. And the enrichment in extractable N in soils, although statistically significant at all three sites, was small. Nutrient enrichment after fire in soils and vegetation is commonly reported to last one to two growing seasons (Christensen, 1994). Our results suggest that nutrient enrichment in soil and vegetation was minor and transitory, likely because nutrient deposition in ash was low.

Above-ground biomass, including litter, was 21.4 Mg ha^{-1} in unburned chaparral growing on soils derived from granitic rocks near our study site at El Mogor, while unburned coastal sage scrub growing on soils derived from basalt, similar to that at Las Chichihuas, was 8.5 Mg ha^{-1} (unpublished data). These values are similar to those reported for chamise chaparral and coastal sage scrub at the IBP study sites near San Diego, California (Rundel, 1983); but values for "mature" Alta California chaparral generally range from 30 to 70 Mg ha^{-1} (Rundel, 1983; DeBano *et al.*, 1977). The chaparral at El Mogor and El Colgado was mature and the fire, which was at times intense, burned for several days during windy "Santa Ana" conditions. Nevertheless,

it is likely that fire intensities at the study sites were low. The unburned chaparral at El Colgado was an "island" which otherwise would have been consumed under windy conditions; the study site at El Mogor was near the fire's margin, and the fire at Las Chichihuas was not extensive.

Results reported in the present study are likely typical of Baja California fires. In contrast with Alta California, where fire suppression has been practiced for nearly a century, wildland fires in Baja California are numerous but small (MINNICH, 1983). Large numbers of fires fragment plant communities into a mosaic of age classes, only some of which can support fire. This process seems to diminish the likelihood of large, intense fires. Because fires in Baja California burn during all weather conditions, not just "Santa Ana" conditions, fire intensities also tend to be lower (MINNICH *et al.,* 1993). It is likely that nutrient losses by volatilization, as well as ash deposition, are generally lower in Baja than in Alta California, both because less fuel is available to burn, and because less of it is consumed by fire.

CONCLUSION

Soil at the coastal scrub site, which was derived from basalt, was more fertile than in the chaparral sites, where soils developed on granitic rocks. In the chaparral sites, total soil P concentrations were low, and similar to those of the typically infertile soils of Mediterranean-climate shrublands of Australia. No significant differences were detected in soil pH, organic C, or electrical conductivity between burned and unburned areas. The only evidence of nutrient enrichment after burning was significantly higher inorganic N in soil at all three sites, and a trend toward higher total cations in the soil solution in the chaparral sites. Nitrogen concentrations were higher in leaves and stems in burned areas, but only briefly during beginning and middle of the first growing season after fire. Our results suggest that nutrient enrichment in soils and vegetation following fire was lower and more transitory than is typically reported for burned shrublands in Alta California. This may have resulted from lower fuel loads and fire intensities, and consequently lower ash deposition. More extensive studies are required to determine how differences in management across the USA-Mexico border have caused Mediterranean-climate ecosystems to diverge.

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